REMARKS

The examiner kindly made suggestions for amendments to the claims to address issues of indefiniteness under 35 U.S.C. 112. Applicant made the suggested amendments except that, for the second suggestion, the term "frame" was believed to be needless and therefore was deleted. There is no reason to distinguish the lift truck from the lift truck frame. Additionally, the term "lifting mast" was changed to "lift mast" because that is the term used in the specification and is believed to be the more conventional term.

35 U.S.C. 112 - Enablement

The examiner rejected claims 1, 2, 4 and 5 as failing to comply with the enablement requirement. The examiner said that the internals of the accelerometer are not shown and appears to be saying that the disclosure does not show how an accelerometer can be used to detect the resultant of the gravitational force and the force of vehicle acceleration.

The examiner is correct in his observation that the accelerometer construction and the manner it is used to detect the resultant of gravity and vehicle acceleration are not disclosed. They were not disclosed as a result of a belief that accelerometers and their use to find a resultant acceleration force have been around so long that this information was well known in the art. As stated in the MPEP: "The specification need not disclose what is well-known to those skilled in the art and preferably omits that which is well-known to those skilled and already available to the public." M.P.E.P. 2164.05(a).

Applicant recognizes that accelerometer technology is just one little piece of the prior art technology that many, and probably most, technical people would have no reason to be familiar with. Applicant's belief that accelerometers and the detection of a resultant acceleration force, including its vector direction, is an old, well known art is based upon the fact that applicant's undersigned attorney has been aware of them for the forty years of his professional life. That belief is reinforced by the fact that Class 73, Measuring and Testing, subclass 488, Speed, velocity or acceleration has subclass 514.01 "Acceleration determination utilizing inertial element", which has under it subclasses 514.01 through 514.38. Additionally, a search of patent specifications on the USPTO web site for the word "accelerometer" turned up over 10,000 patents since 1976.

The examiner kindly suggested that applicant could overcome this rejection by submitting technical literature published before the filing date of this application and specifically mentioned the particular model cited in the application by applicant. The specification or data booklet for that device used by the inventor and published before the application was filed is appended to this amendment.

It might be helpful to explain how a simple accelerometer senses the resultant of the gravitational force and vehicle acceleration. Applicant apologizes if this discussion is merely describing what the examiner already knows. Applicant may be missing the point of the examiner's rejection.

An accelerometer detects the resultant of gravity and vehicle acceleration in the same way that a weight hanging on a string causes the string to always align along that resultant. In fact, the invention can be thought of as aligning the cargo support of a lift

truck perpendicular to such a string. The force of gravity is an acceleration force commonly represented in classical physics books as g. It is approximately 32.2 ft/sec^2. In accordance with F=ma, the gravitational force applied to a mass is its mass multiplied by g. The force applied to the same mass by vehicle acceleration is equal to that mass multiplied by the vehicle acceleration. A common form of accelerometer is a mass suspended by springs with a detector to measure the movement of the mass against those springs along one, two or three axes. That is the type of accelerometer used by the inventor and is described as such on page 7 of the appended booklet. Since the mass of the accelerometer moves in a direction away from the resultant force of the gravitational and vehicle acceleration forces, the accelerometer reads the direction (and the magnitude) of the resultant. In fact, the accelerometer is only able to read the resultant. It can not read the vehicle acceleration component and the gravity component separately because the suspended mass can only respond to the resultant force.

The examiner accurately observed, in the approximately bottom one-third of page 4 of the office action, that a two axis accelerometer would be limited as compared to a three axis accelerometer. However, the examiner said the accelerometer "would be limited to sensing less than all of the components of the forces associated with the gravitational acceleration *and* that of the vehicle's travel acceleration." It therefore may be important to note that the accelerometer is incapable of measuring either individual gravitational acceleration *or* vehicle travel acceleration component. Except for a particular alignment of the accelerometer, the accelerometer can not distinguish between gravitational force and vehicle acceleration force and does not need to. The mass in the

accelerometer moves as it is forced by the resultant. It is true that an accelerometer detects components of that resultant but those components are the components along the x and y axis (or x, y and z axis of a three axis accelerometer) of the accelerometer. Because the x, y and z axes are not necessarily aligned with horizontal or vertical, the components detected by the accelerometer are not necessarily the gravitational and vehicle acceleration forces and do not need to be.

The examiner also correctly observed that a two axis accelerometer may not be able to take into account acceleration transverse to the vehicle. But lift trucks of the prior art ordinarily have a mast, to which the cargo support is attached, that tilts only in the fore and aft direction. So a two axis accelerometer is all that is needed and is what the accelerometer cited in applicant's specification is. See page 1 of the appended booklet.

The examiner further said that applicant does not disclose the orientation in which the accelerometer is attached to the mast, nor in which direction the resultant is capable of being detected.

The examiner is correct that the mounting orientation is not disclosed. The reason is that it does not matter except that the plane of the axes of a two axis accelerometer is aligned so that it can detect the resultant of gravitation (known to be generally vertical and therefore perpendicular to the plane of the wheels) and vehicle acceleration (known to be generally horizontal and aligned parallel to the fore and aft longitudinal axis of the vehicle). That does not mean that the axes of the accelerometer must be aligned along these axes because the accelerometer does not need to separately detect and distinguish gravitational acceleration force from vehicle acceleration force. As well known to those

in the art from vector analysis, if the orientation of the accelerometer axes relative to the vehicle is known, common trigonometric relationships can be used to translate the resultant direction seen at the accelerometer to the resultant direction with respect to the vehicle.

With respect to the direction the resultant is capable of being detected, applicant clearly discloses that he wants to detect the resultant of gravitational force and the vehicle acceleration force. A person skilled in the art of accelerometers would know that gravitational force is perpendicular to the wheels of the vehicle. He or she would also know that vehicle acceleration force is parallel to the fore and aft longitudinal axis of the vehicle. From that a person skilled in the art could easily determine from vector analysis, statics and dynamics, without undue experimentation, that the resultant of those forces will be in a plane parallel to that longitudinal axis and perpendicular to the plane of the wheels. More specifically, they would know that the resultant would be in that plane and in the range between 90° directly aft and 90° directly forward. From that, basic accelerometer principles tell a person skilled in the art that the axes of the accelerometer are preferably in that plane. In other words, a person skilled in the art of accelerometers, after being told that the accelerometer needs to measure the resultant of the force of gravity and the force of vehicle acceleration, would know that those are the vector directions, and therefore would know the directions that acceleration is to be measured and therefore would know how to align the accelerometer.

Because accelerometers and their operation were well known long before applicant's application was filed and the above explanation is classical physics well

known to those skilled in the art, applicant's disclosure is believed to have enabled one skilled in the art to make and use the invention. In the event applicant's undersigned attorney seems to the examiner to not have addressed something of concern to the examiner, applicant's requests a phone call from the examiner and a telephone interview.

35 U.S.C. 103

Before discussing the rejection made by the examiner, applicant would point out a simple and very important fact. An accelerometer is an important element of applicant's invention and applicant's claims. Neither reference discloses an accelerometer or the use of an accelerometer on a lift truck. Applicant's undersigned counsel read through the Kim reference and painfully read through the lengthy Avitan reference. No accelerometer was found.

Avitan discusses acceleration, but it is discussed in terms of its effect on causing a vehicle to tip over and limiting acceleration. Nowhere in Avitan does he say that he has an accelerometer. Nowhere does he sense acceleration. And most importantly, nowhere does he detect the resultant of gravity and vehicle acceleration. The text cited by the examiner in columns 7-9 is Avitan's analysis of vehicle instability and says only that acceleration was taken into account in that analysis of what makes a vehicle tip over. Nowhere in the drawings is there an input for acceleration. The flow chart of Fig. 5 shows the steps of storing many sensed values and none are acceleration. Avitan's summary in column 8 cites several "factors" he takes into account and none are acceleration. Avitan says that truck acceleration is limited but that is not sensing. He also

says truck acceleration can be "requested", but that means that the driver instructs the vehicle to go at a requested acceleration. Avitan senses conditions of the vehicle. Of course truck acceleration could be computed from an input of truck speed over time and differentiating the speed with respect to time. But that clearly is not use of an accelerometer and furthermore would not detect the resultant of the force of gravity and vehicle acceleration.

Kim also does not disclose an accelerometer or detecting acceleration. Kim does detect speed, but that is not acceleration and also would not detect the same resultant as detected by applicant's accelerometer. Kim is admittedly difficult to understand, but its vagueness should not be a basis for attributing disclosures that are not there. Kim says that he detects "tilt angle". Ordinarily, the tilt angle of a lift truck mast is the angle of the mast with respect to the vehicle. This is confirmed by Kim's statement, in column 3, lines 39-41, that a tilt angle is measured relative to the horizontal surface of the equipment front. Therefore, it is clear that Kim is measuring tilt angle with respect to the equipment, not the horizon.

Because neither reference teaches an accelerometer, the invention is not obvious because the requirements for obviousness are not met. Those requirements are:

> "First, there must be some suggestion or motivation, either in the references themselves or in the knowledge generally available to one of ordinary skill in the art, to modify the reference or to combine reference teachings. Second, there must be a reasonable expectation of success. Finally, the prior art reference (or references when combined) must teach or suggest all the claim limitations. The teaching or suggestion to make the claimed combination and the reasonable expectation of success must both be found in the prior art, and not based on applicant's disclosure." MPEP 2142

Applicant turns now to the office action. Although applicant has no reason to believe that the examiner and applicant have different understandings of some of the terminology, before addressing the examiner's comments, applicant would like to be certain of that by making a few observations. Applicant asks the examiner to call to applicant's attention any difference in the use or understanding of these terms. Speed and velocity are believed different words for the identical thing in the context of this invention. Since deceleration is just a negative value of acceleration, the word acceleration is used for both. Of course acceleration is different from velocity because acceleration is the rate of change of velocity or, in mathematical terms, acceleration is the first derivative of velocity with respect to time.

Although it appears from the Office Action that the examiner understands the invention, it might be helpful to briefly outline its basic concepts. Applicant's invention is directed to preventing a cargo that is resting upon the cargo support of a lift truck, from falling off <u>as a result of excessive acceleration</u> of the lift truck. That is because a cargo resting upon a stationary horizontal surface is secure and stabilized but, if that surface is maintained horizontal but is also accelerated, the load may slide off as a result of the F=ma force applied horizontally to the load as a result of the acceleration. For example, a load on a lift truck may slide forwardly and fall off if the lift truck is traveling with a forward velocity but slowing down with an excessive negative acceleration. The load may also fall off forwardly if the lift truck accelerates excessively in its reverse direction. Applicant's solution is a feedback control system that has an accelerometer that senses the resultant of (1) the gravitational force applied to the load and (2) the F=ma force

resulting from the vehicle acceleration. The output from the feedback control system is connected to the mast tilt actuators and tilts the cargo support surface back so that the cargo support is perpendicular to the resultant sensed by the accelerometer. For an oppositely directed F=ma force that results from an oppositely directed vehicle acceleration, the support surface is tilted in the opposite direction, forwardly to attain the same relationship of the resultant to the support platform.

The examiner's observations of what is shown and what is not shown in the Kim reference appear accurate to applicant. The Kim reference is directed to preventing a cargo that is resting upon the cargo support of a lift truck, from falling off <u>as a result of the lift truck traveling over a hill</u> (i.e. tilting from horizontal) which causes its cargo support to become inclined to horizontal allowing the cargo to slide off. Kim solves the problem by tilting the cargo support with respect to the lift truck so that the cargo support is <u>maintained</u> in a <u>horizontal</u> orientation. Applicant tilts the cargo support away from horizontal in response to vehicle acceleration. Kim's disclosure has nothing to do with <u>acceleration</u> of the vehicle, only its orientation with respect to the horizon. The examiner's last sentence on page 6 of the office action indicates that the examiner appreciates this difference.

Before discussing the Avitan reference, applicant notes that the examiner used forms of the verb "stabilize" when describing the operation of the Kim device. That is no problem so long as it is recognized that "stabilize" is a broad term and that Kim and applicant are stabilizing the load against the two different problems or instabilities described above and in the two different ways described above. Specifically, Kim

maintains the cargo support horizontal to compensate for changes in the orientation of the lift truck with respect to the horizon and applicant tilts the cargo support away from horizontal to compensate for lift truck acceleration.

Avitan et al. deals with vehicle stability, namely preventing the entire lift truck with a load from tipping over. Avitan senses a plurality of conditions, computes a speed limit from those sensed conditions, prevents operation of the lift truck at a speed that exceeds the speed limit and, if the lift truck is going faster than the limit, the Avitan system reduces vehicle speed down to the limit.

The only effect the Avitan system has on the lift truck is to limit its speed and acceleration and actuate signals or alarms. Avitan makes no changes to the mechanical configuration or arrangement or "conditions" of any component part of the truck. Avitan does not tilt anything. Avitan does not have a control system output connected to the mast tilt actuators and does not tilt the mast or cargo support. Avitan just senses conditions and limits speed and acceleration. The operator controls all other conditions, including mast position and cargo platform height. The Avitan system merely senses where the operator set those things and calculates a maximum speed and acceleration that is safe for those conditions. Consequently, Avitan does not do, and Avitan does not show, what the examiner recognized (in the last sentence on page 6 of the office action) was not shown in Kim.

Applicant agrees that the examiner's observations of what is described in Avitan are accurate. Avitan does, as the examiner states, sense a variety of operating parameters to establish a composite center of gravity. But applicant's invention does not deal with or

take into account the position of the center of gravity. Applicant is tilting the cargo support so that it is perpendicular to the resultant of the force of gravity and the vehicle acceleration. Avitan does set a control limit on the operation of the lift truck, but that control limit is a limit on vehicle velocity and vehicle acceleration. Applicant does not claim any limiting of velocity or acceleration. Avitan does not tilt the cargo platform for any reason. Avitan does deal with force vectors and reference vectors, but he uses them for entirely different purposes to accomplish an entirely different result and utility.

The point is that, although Avitan does what the examiner says it does, Avitan does not do what the examiner says is not shown in Kim. Neither Avitan nor Kim describe the invention applicant claims. And, as stated above, neither Avitan nor Kim teach the use of an accelerometer that senses the resultant of gravity force and vehicle acceleration force.

For these reasons, the applicant's invention is not obvious from the prior art, and therefore reconsideration and allowance are respectfully requested.

The examiner is authorized to communicate with the undersigned attorney by email by the following recommended authorization language: Recognizing that Internet communications are not secure, I hereby authorize the USPTO to communicate with me concerning any subject matter of this application by electronic mail. I understand that a copy of these communications will be made of record in the application file. (Authorization pursuant to MPEP 502.03.)

The Commissioner is authorized to charge Deposit Account No. 13-3393 for any insufficient fees under 37 CFR §§ 1.16 or 1.17, or credit any overpayment of fees.

Respectfully submitted,

5-4-2006
Date of Signature

Frank H. Foster,
Reg. No. 24,560
KREMBLAS, FOSTER, PHILLIPS & POLLICK
7632 Slate Ridge Blvd.
Reynoldsburg, OH 43068
Voice: 614/575-2100
Fax: 614/575-2149
email: ffoster@ohiopatent.com

Enclosures Faxed: Attachment to Response (12 pgs)
Petition for Extension of Time – 1 month (1 pg)
Fee Transmittal Form (1 pg)
Credit Card Payment Form (1 pg)

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ANALOG DEVICES

Low Cost, Ultracompact ±2 *g* Dual-Axis Accelerometer

ADXL311

FEATURES

Low cost
High resolution
Dual-axis accelerometer on a single IC chip
5 mm × 5 mm × 2 mm CLCC package
Low power < 400 μA (typ)
X-axis and Y-axis aligned to within 0.1° (typ)
BW adjustment with a single capacitor
Single-supply operation
High shock survival

APPLICATIONS

Tilt and motion sensing in cost-sensitive applications
Smart handheld devices
Computer security
Input devices
Pedometers and activity monitors
Game controllers
Toys and entertainment products

GENERAL DESCRIPTION

The ADXL311 is a low cost, low power, complete dual-axis accelerometer with signal conditioned voltage outputs, all on a single monolithic IC. The ADXL311 is built using the same proven iMEMS® process used in over 100 million Analog Devices accelerometers shipped to date, with demonstrated 1 FIT reliability (1 failure per 1 billion device operating hours).

The ADXL311 will measure acceleration with a full-scale range of ±2 *g*. The ADXL311 can measure both dynamic acceleration (e.g., vibration) and static acceleration (e.g., gravity). The outputs are analog voltages proportional to acceleration.

The typical noise floor is 300 $\mu g/\sqrt{Hz}$ allowing signals below 2 m*g* (0.1° of inclination) to be resolved in tilt sensing applications using narrow bandwidths (10 Hz).

The user selects the bandwidth of the accelerometer using capacitors C_X and C_Y at the X_{FILT} and Y_{FILT} pins. Bandwidths of 1 Hz to 2 kHz may be selected to suit the application.

The ADXL311 is available in a 5 mm × 5 mm × 2 mm 8-terminal hermetic CLCC package

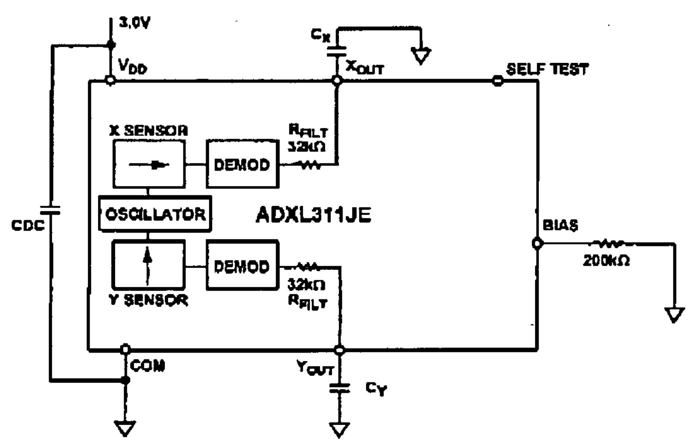

Figure 1. Functional Block Diagram

One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106, U.S.A.
Tel: 781.329.4700 www.analog.com
Fax: 781.326.8703

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REVISION HISTORY

7/03—Data sheet changed from Rev. 0 to Rev. A.
Change to OUTLINE DIMENSIONS 10

Revision 0: Initial Version

SPECIFICATIONS

Table 1. $T_A = 25°C$, $V_{DD} = 3$ V, $R_{BIAS} = 125$ kΩ, Acceleration = 0 *g*, unless otherwise noted.)

Parameter	Conditions	Min	Typ	Max	Units
SENSOR INPUT	Each Axis				
Measurement Range			±2		*g*
Nonlinearity	Best Fit Straight Line		0.2		% of FS
Aligment Error[1]			±1		Degrees
Aligment Error	X Sensor to Y Sensor		0.01		Degrees
Cross Axis Sensitivity[2]			±2		%
SENSITIVITY	Each Axis				
Sensitivity at X_{FILT}, Y_{FILT}	$V_{DD} = 3$ V	140	167	195	mV/*g*
Sensitivity Change due to Temperature[3]	Delta from 25°C		−0.025		%/°C
ZERO *g* BIAS LEVEL	Each Axis				
0 *g* Voltage X_{FILT}, Y_{FILT}	$V_{DD} = 3$ V	1.2	1.5	1.8	V
0 *g* Offset vs. Temperature	Delta from 25°C		2.0		m*g*/°C
NOISE PERFORMANCE					
Noise Density	@25°C		300		μ*g*/√Hz RMS
FREQUENCY RESPONSE					
3 dB Bandwidth	At Pins X_{FILT}, Y_{FILT}		6		kHz
Sensor Resonant Frequency			10		kHz
FILTER					
R_{FILT} Tolerance	32 kΩ Nominal		±15		%
Minimum Capacitance	At Pins X_{FILT}, Y_{FILT}	1000			pF
SELF TEST					
X_{FILT}, Y_{FILT}	Self Test 0 to 1		45		mV
POWER SUPPLY					
Operating Voltage Range		2.7		5.25	V
Quiescent Supply Current			0.4	1.0	mA
Turn-On Time			$160 \times C_{FILT} + 0.3$		ms
TEMPERATURE RANGE					
Operating Range		0		70	°C

[1] Alignment error is specified as the angle between the true and indicated axis of sensitivity (Figure 1).
[2] Cross axis sensitivity is the algebraic sum of the alignment and the inherent sensitivity errors.
[3] Defined as the output change from ambient to maximum temperature or ambient to minimum temperature.

ABSOLUTE MAXIMUM RATINGS

Table 2.

Parameter	Rating
Acceleration (Any Axis, Unpowered)	3,500 *g*, 0.5 ms
Acceleration (Any Axis, Powered, V_{DD} = 3 V)	3,500 *g*, 0.5 ms
V_{DD}	−0.3 V to +0.6 V
Output Short-Circuit Duration, (Any Pin to Commom)	Indefinite
Operating Temperature Range	−55°C to +125°C
Storage Temperature	−65°C to +150°C

Stresses above those listed under Absolute Maximum Ratings may cause permanent damage to the device. This is a stress rating only and functional operation of the device at these or any other conditions above those indicated in the operational section of this specification is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 3. Package Characteristics

Package Type	θ_{JA}	θ_{JC}	Device Weight
8-Lead CLCC	120°C/W	TBD°C/W	<1.0 gram

TYPICAL PERFORMANCE CHARACTERISTICS

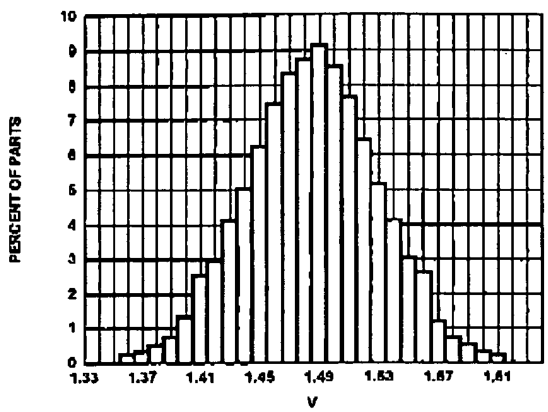

Figure 2. X-Axis Zero g BIAS Output Distribution

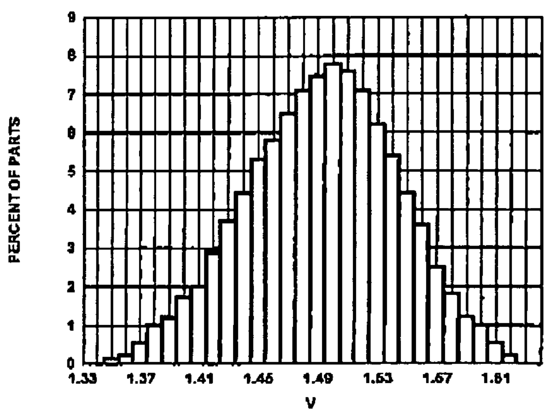

Figure 3. Y-Axis Zero g BIAS Output Distribution

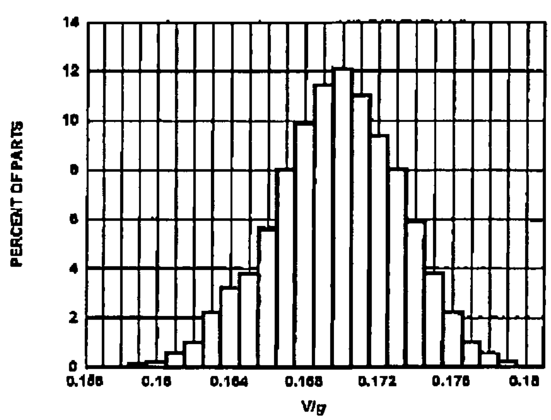

Figure 4. X-Axis Output Sensitivity Distribution at X_{OUT}

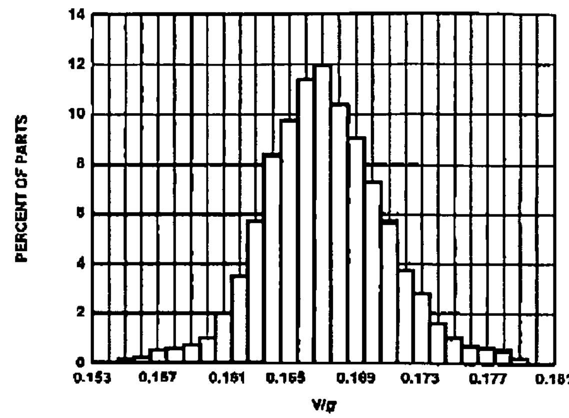

Figure 5. Y-Axis Sensitivity Distribution at Y_{OUT}

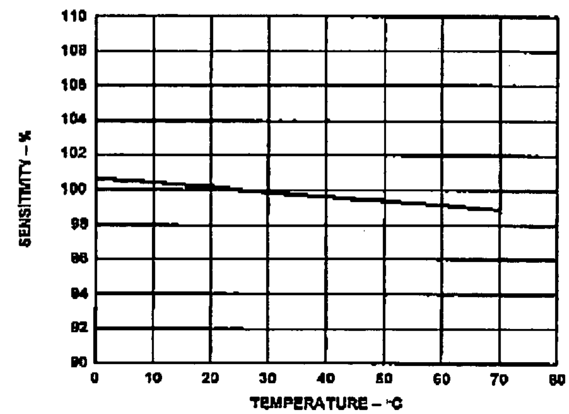

Figure 6. Normalized Sensitivity vs. Temperature

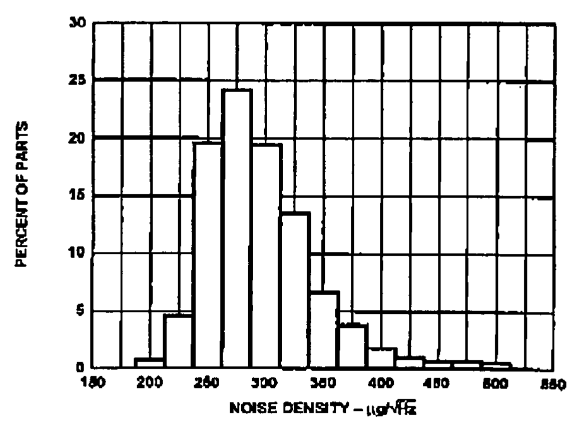

Figure 7. Noise Density Distribution

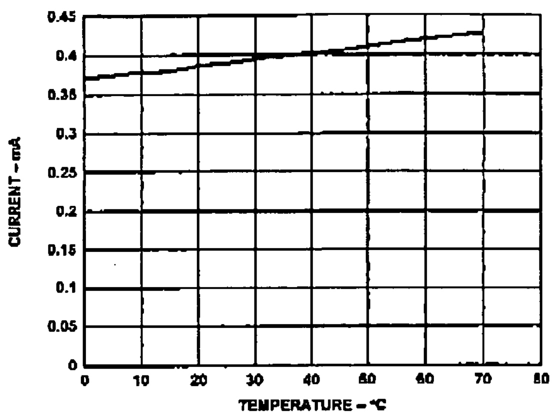

Figure 8. Typical Supply Current vs. Temperature

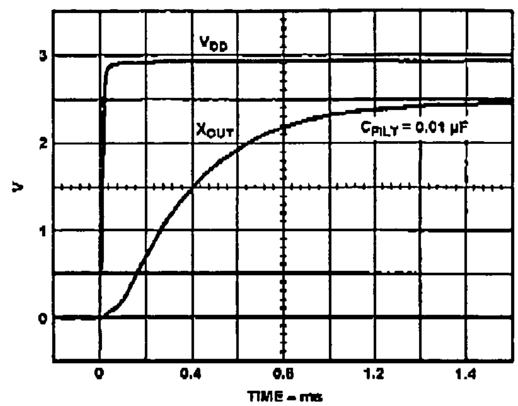

Figure 9. Typical Turn-On Time

THEORY OF OPERATION

The ADXL311 is a complete, dual-axis acceleration measurement system on a single monolithic IC. It contains a polysilicon surface-micromachined sensor and signal conditioning circuitry to implement an open-loop acceleration measurement architecture. The output signals are analog voltage proportional to acceleration. The ADXL311 is capable of measuring both positive and negative accelerations to at least ±2 *g*. The accelerometer can measure static acceleration forces, such as gravity, allowing it to be used as a tilt sensor.

The sensor is a surface-micromachined polysilicon structure built on top of the silicon wafer. Polysilicon springs suspend the structure over the surface of the wafer and provide a resistance against acceleration forces. Deflection of the structure is measured using a differential capacitor that consists of independent fixed plates and central plates attached to the moving mass. The fixed plates are driven by 180° out of phase square waves. Acceleration will deflect the beam and unbalance the differential capacitor, resulting in an output square wave whose amplitude is proportional to acceleration. Phase sensitive demodulation techniques are then used to rectify the signal and determine the direction of the acceleration.

The output of the demodulator is amplified and brought off-chip through a 32 kΩ resistor. At this point, the user can set the signal bandwidth of the device by adding a capacitor. This filtering improves measurement resolution and helps prevent aliasing.

Applications

POWER SUPPLY DECOUPLING

For most applications, a single 0.1 µF capacitor, CDC, will adequately decouple the accelerometer from noise on the power supply. However, in some cases, particularly where noise is present at the 100 kHz internal clock frequency (or any harmonic thereof), noise on the supply may cause interference on the ADXL311 output. If additional decoupling is needed, a 100 Ω (or smaller) resistor or ferrite beads may be inserted in the supply line of the ADXL311. Additionally, a larger bulk bypass capacitor (in the 1 µF to 4.7 µF range) may be added in parallel to CDC.

SETTING THE BANDWIDTH USING C_X AND C_Y

The ADXL311 has provisions for bandlimiting the X_{OUT} and Y_{OUT} pins. Capacitors must be added at these pins to implement low-pass filtering for antialiasing and noise reduction. The equation for the 3 dB bandwidth is

$$F_{-3dB} = 1/\left(2\pi(32\ \text{k}\Omega) \times C_{(X,Y)}\right)$$

or, more simply

$$F_{-3dB} = 5\ \mu\text{F} / C_{(X,Y)}$$

The tolerance of the internal resistor (R_{FILT}) can vary typically as much as ±15% of its nominal value of 32 kΩ; thus, the bandwidth will vary accordingly. A minimum capacitance of 1000 pF for C_X and C_Y is required in all cases.

Table 4. Filter Capacitor Selection, C_X and C_Y

Bandwidth	Capacitor (µF)
10 Hz	0.47
50 Hz	0.10
100 Hz	0.05
200 Hz	0.027
500 Hz	0.01
5 kHz	0.001

SELF TEST

The ST pin controls the self-test feature. When this pin is set to V_{DD}, an electrostatic force is exerted on the beam of the accelerometer. The resulting movement of the beam allows the user to test if the accelerometer is functional. The typical change in output will be 270 m*g* (corresponding to 45 mV). This pin may be left open circuit or connected to common in normal use.

R_{BIAS} SELECTION

A bias resistor (R_{BIAS}) must always be used. If no resistor is present, the ADXL311 may appear to work but will suffer degraded noise performance. The value of the resistor used is not critical. Any value from 50 kΩ to 2 MΩ can be used. Using a 2 MΩ resistor rather than a 50 kΩ will save roughly 25 µA of supply current.

Design Trade-Offs for Selecting Filter Characteristics: The Noise/BW Trade-Off

The accelerometer bandwidth selected will ultimately determine the measurement resolution (smallest detectable acceleration). Filtering can be used to lower the noise floor, which improves the resolution of the accelerometer. Resolution is dependent on the analog filter bandwidth at X_{OUT} and Y_{OUT}.

The output of the ADXL311 has a typical bandwidth of 5 kHz. The user must filter the signal at this point to limit aliasing errors. The analog bandwidth must be no more than half the A/D sampling frequency to minimize aliasing. The analog bandwidth may be further decreased to reduce noise and improve resolution.

The ADXL311 noise has the characteristics of white Gaussian noise that contributes equally at all frequencies and is described in terms of $\mu g/\sqrt{\text{Hz}}$, i.e., the noise is proportional to the square

root of the bandwidth of the accelerometer. It is recommended that the user limit bandwidth to the lowest frequency needed by the application, to maximize the resolution and dynamic range of the accelerometer.

With the single pole roll-off characteristic, the typical noise of the ADXL202E is determined by

$$RMS\ NOISE = \left(300\ \mu g/\sqrt{\text{Hz}}\right) \times \left(\sqrt{BW} \times 1.6\right)$$

At 100 Hz the noise will be

$$RMS\ NOISE = \left(300 \mu g/\sqrt{\text{Hz}}\right) \times \left(\sqrt{100} \times 1.6\right) = 3.8\ mg$$

Often the peak value of the noise is desired. Peak-to-peak noise can only be estimated by statistical methods. Table 5 is useful for estimating the probabilities of exceeding various peak values, given the rms value.

Table 5. Estimation of Peak-to-Peak Noise

Peak-to-Peak Value	% of Time That Noise Will Exceed Nominal Peak-to-Peak Value
2 × RMS	32
4 × RMS	4.6
6 × RMS	0.27
8 × RMS	0.006

The peak-to-peak noise value will give the best estimate of the uncertainty in a single measurement. Table 6 gives the typical noise output of the ADXL311 for various C_X and C_Y values.

Table 6. Filter Capacitor Selection (C_X, C_Y)

Bandwidth (Hz)	C_X, C_Y (µF)	RMS Noise (m*g*)	Peak-to-Peak Noise Estimate (m*g*)
10	0.47	1.2	7.2
50	0.1	2.7	16.2
100	0.047	3.8	22.8
500	0.01	8.5	51

USING THE ADXL311 WITH OPERATING VOLTAGES OTHER THAN 3 V

The ADXL311 is tested and specified at V_{DD} = 3 V; however, it can be powered with V_{DD} as low as 2.7 V or as high as 5.25 V. Some performance parameters will change as the supply voltage is varied.

The ADXL311 output is ratiometric, so the output sensitivity (or scale factor) will vary proportionally to supply voltage. At V_{DD} = 5 V the output sensitivity is typically 312 mV/*g*.

The zero *g* bias output is also ratiometric, so the zero *g* output is nominally equal to $V_{DD}/2$ at all supply voltages.

The output noise is not ratiometric but absolute in volts; therefore, the noise density decreases as the supply voltage increases. This is because the scale factor (mV/*g*) increases while the noise voltage remains constant.

The self-test response is roughly proportional to the square of the supply voltage. At V_{DD} = 5 V, the self-test response will be approximately equivalent to 800 m*g* (typical).

The supply current increases as the supply voltage increases. Typical current consumption at V_{DD} = 5 V is 600 µA.

Using the ADXL311 as a Dual-Axis Tilt Sensor

One of the most popular applications of the ADXL311 is tilt measurement. An accelerometer uses the force of gravity as an input vector to determine the orientation of an object in space.

An accelerometer is most sensitive to tilt when its sensitive axis is perpendicular to the force of gravity, i.e., parallel to the earth's surface. At this orientation, its sensitivity to changes in tilt is highest. When the accelerometer is oriented on axis to gravity, i.e., near its +1 *g* or −1 *g* reading, the change in output acceleration per degree of tilt is negligible. When the accelerometer is perpendicular to gravity, its output will change nearly 17.5 m*g* per degree of tilt, but at 45° degrees, it is changing only at 12.2 m*g* per degree and resolution declines.

DUAL-AXIS TILT SENSOR: CONVERTING ACCELERATION TO TILT

When the accelerometer is oriented so both its X-axis and Y-axis are parallel to the earth's surface, it can be used as a two axis tilt sensor with a roll axis and a pitch axis. Once the output signal from the accelerometer has been converted to an acceleration that varies between −1 *g* and +1 *g*, the output tilt in degrees is calculated as follows:

$$PITCH = ASIN\left(A_X/1\ g\right)$$

$$ROLL = ASIN\left(A_Y/1\ g\right)$$

Be sure to account for overranges. It is possible for the accelerometers to output a signal greater than ±1 *g* due to vibration, shock, or other accelerations.

PIN CONFIGURATION AND FUNCTIONAL DESCRIPTIONS

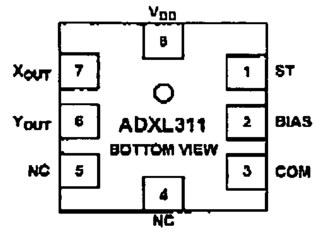

Figure 10. 8-Lead CLCC

Table 7. Pin Function Descriptions—8-Lead CLCC

Pin No.	Mnemonic	Description
1	ST	Self Test
2	BIAS	Bias Resistor (≈200 kΩ)
3	COM	Common
4	NC	Do Not Connect
5	NC	Do Not Connect
6	Y_{OUT}	Y Channel Output
7	X_{OUT}	X Channel Output
8	V_{DD}	2.7 V to 5.25 V

OUTLINE DIMENSIONS

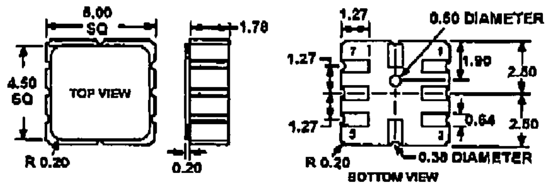

Figure 11. 8-Terminal Ceramic Leadless Chip Carrier [CLCC]
(E-8)
Dimensions shown in millimeters

ESD CAUTION

ESD (electrostatic discharge) sensitive device. Electrostatic charges as high as 4000 V readily accumulate on the human body and test equipment and can discharge without detection. Although this product features proprietary ESD protection circuitry, permanent damage may occur on devices subjected to high energy electrostatic discharges. Therefore, proper ESD precautions are recommended to avoid performance degradation or loss of functionality.

Ordering Guide

ADXL311Products	Number of Axes	Specified Voltage	Temperature Range
ADXL311JE	2	3 V	0°C to 70°C
ADXL311JE–REEL	2	3 V	0°C to 70°C
ADXL311EB Evaluation Board			

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